TP 4869 E

Axle Angle of Attack Comparison Frame-Braced vs. Conventional Freight Truck

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AXLE ANGLE OF ATTACK COMPARISON

FRAME BRACED VS CONVENTIONAL FREIGHT TRUCK

by

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Kingston, Ontario
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17. Abstract

This report describes the method and the results of performing wheel-to-rail angle of attack measurements. The measurements were carried out on the leading axle of the frame-braced modified and unmodified Barber S-2 three-piece freight trucks under both loaded and empty 100-ton gondola cars. The measurements were performed, using a micro-computer controlled electro-mechanical system on a 19 degree (92 m, 303 ft. mean radius) curve, under both wet and dry rail conditions in the yards at the Ontario Northland Railway. The results show that the frame-braced truck steered consistently better (23 percent minimum) than the unmodified truck. It was shown that under wet rail conditions, the improvement in steering of the frame-braced truck over the conventional truck was nearly 100 percent. It was also shown that the frame-braced trucks steered better under the empty car, than under the loaded car, while the conventional trucks showed little change.

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17. Résumé

Ce rapport décrit la méthode utilisée pour mesurer l'angle d'inscription en courbe des roues d'un véhicule ferroviaire. Il présente aussi le résultat des mesures faites relativement à l'essieu directeur de bogies Barber S-2 modifiés (c'est-à-dire à liaison croisée des longerons), et non modifiés, équipant des wagons-trémies de 100 tonnes, chargés ou vides. Les mesures, prises au moyen d'un appareillage électromécanique commandé par micro-ordinateur, ont été faites à la fois par temps sec et par temps pluvieux, dans une courbe de 19º (rayon de courbure moyen de 93 m ou 303 pi) d'une gare de triage de l'Ontario Northland Railway. Les résultats montrent que le bogie modifié se comportait toujours mieux (par une marge minimum de 23 p. cent) que le bogie non modifié. On a aussi constaté que le premier apportait une amélioration approchant 100 p. cent par rapport à la tenue du second par temps pluvieux. Autre constatation: le bogie modifié s'inscrivait mieux dans la courbe sous wagon lège que sous wagon chargé, tandis que du côté des Barber S-2 non modifiés, cela ne faisait aucune différence.

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Bogie à liaison croisée des longerons, angle d'inscription en courbe, interaction roues/rail	Un nombre limité d'exemplaires sont disponible au CDT

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MODIFIED VS. UNMODIFIED FRAME BRACED FREIGHT TRUCK

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SUMMARY

The angle of attack of the #1 axle of a freight car fitted with modified frame-braced trucks was measured and compared with the #1 axle of a similar car with unmodified trucks over a range of low speeds, empty and with rated load, in a 19° curve.

The modified truck consistently demonstrated lower angle of attack than the unmodified truck, in the range 1.23:1 to 2.22:1.

1.0 BACKGROUND

1.1 ANGLE OF ATTACK

The axle of angle of attack is defined as the measured angle between the wheel radial (rolling) plane and the rail longitudinal axis. Perfect alignment of a wheel on rail is denoted by an angle of attack of zero. Angles greater than zero (in absolute terms) result in wheel/rail slip which produces wheel and rail wear. Although the true relationship between angle of attack and wear is not fully understood, increasing angles of attack produce increased wear.

1.2 THEORY

Linear lumped mass/spring/damper mathematical models of the modified and unmodified vehicles were formulated and quasi-linear curving analyses were carried out.

1.3 PROGRAM

The so-called Frame Braced Freight Truck Program was the result of a study carried out at UTDC R&D Ltd. to assess the effects of cross-bracing the axles of a freight truck. It was found that bracing the sideframes and softening the primary suspension of those same freight trucks would achieve a major portion of the cross-bracing effects. The Program was instituted to confirm those results. The measurement of the wheel/rail angle of attack was an integral part of that confirmation.

1.4 TEST

Two Barber S-2 freight trucks were modified, by adding frame braces and rubber primary suspension, and fitted to a

"100 ton" gondola car. Vehicle weight was 30940 kg (68200 lbs) empty; 117600 kg (259200 lbs) fully loaded.

In addition, two Barber S-2 trucks, unmodified, were fitted to a similar "100 ton" gondola car. Vehicle weight was 30220 kg (66600 lbs) empty; 106440 kg (234600 lbs) fully loaded.

The two cars were coupled as a married pair and axles designated as shown in Figure 1.1.

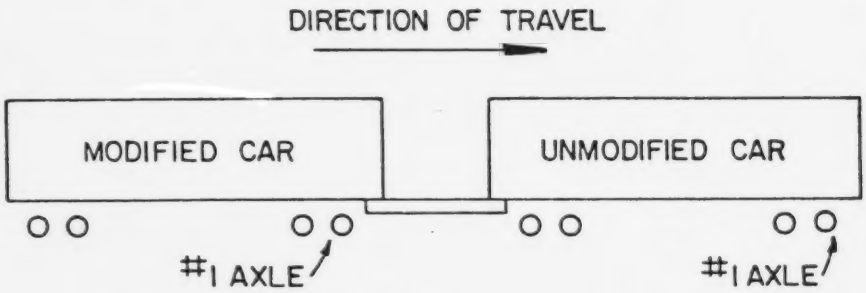


FIGURE 1.1: TEST CONSIST

2.0 PURPOSE

To measure the angle of attack of the #1 axle of both the modified and unmodified cars and for each in both the fully laden and empty conditions while negotiating a track of known curvature.

3.0 INSTRUMENTATION AND EQUIPMENT

3.1 LIST AND DESCRIPTION

A. Specially designed and built assemblies to mount on-board axle position reference arms. Qty 4 (Figure 3.1).

B. Axle bearing adapters specially modified to accept "A" above. Qty 4 (Figure 3.1).

C. Axle angle of attack measuring equipment comprising trackside sensors Figure 3.2 Qty 9 with computer, timers and necessary peripherals.

D. Specially designed and built brackets to mount trackside sensors. Qty. 6.

3.2 CALIBRATION PROCEDURES

3.2.1 On-board reference arms were positioned relative to the axles as follows:

- Axle end-cap was removed exposing the central conical depression used during axle manufacture.
- By means of a round bar machined such that one end was a precision fit in the axle depression while a fine slot marked the diameter of the opposite end, a plumb line was dropped from the axle centre line (Figure 3.1).
- The reference edge of the on-board axle position arm was carefully adjusted to coincide with axle centre-line and locked in position.

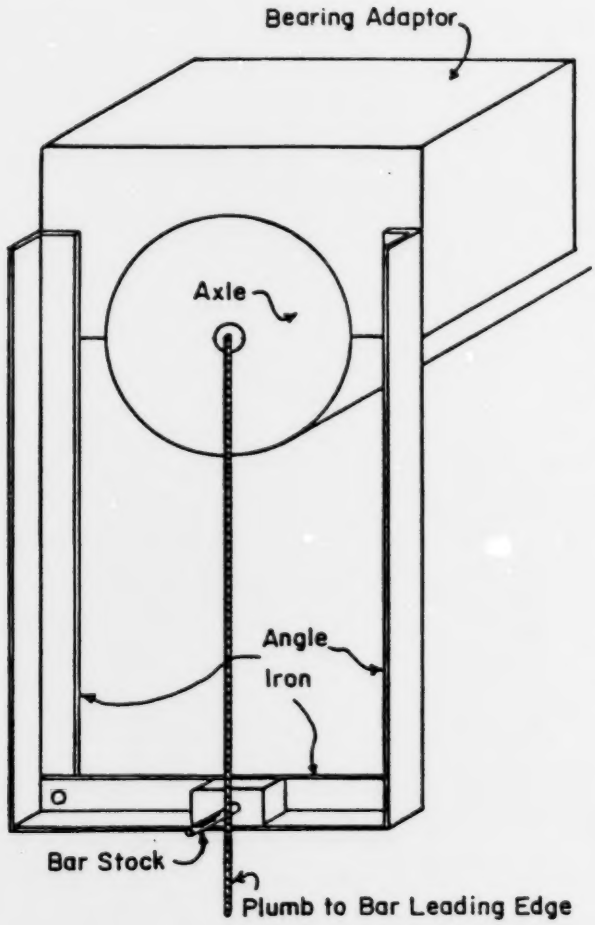


FIGURE 3.1: AXLE-BORNE STRIKERS

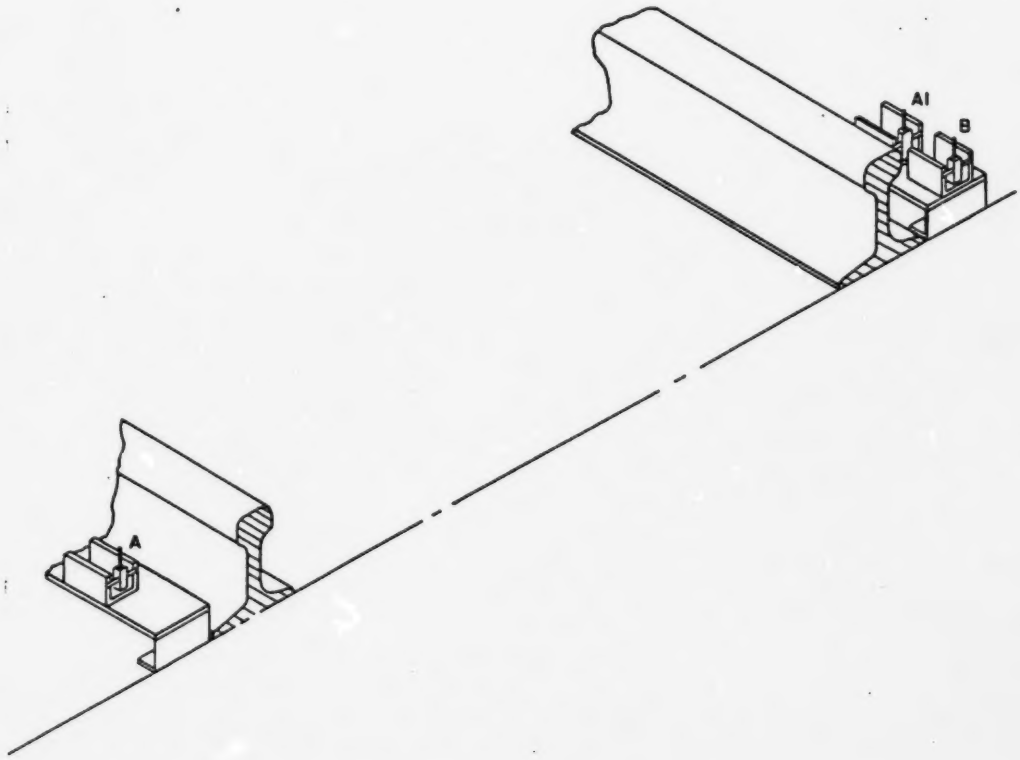


FIGURE 3.2: TRACKSIDE SENSOR SET-UP

- This procedure was completed for each end of both axles to be tested.

3.2.2 Trackside sensors were located as follows:

- An elementary geometrical method was used to establish the line radius to the track at the test location. Specifically the method yields the perpendicular bisecting a 2.5 metre chord of the inner running rail.

- Two sensors were fixed in place on the radius line, one on each side of the track, outboard of the running rails. The distance between them was measured and noted.

- A third sensor was fixed in place approximately 30 cm ahead of the outer radial sensor. The distance between the two was measured and noted.

- The above procedure was carried out for two further test locations at intervals of approximately 2.5 metres.

4.0 TEST SET-UP

4.1 The tests were carried out at the Ontario Northland Railway North Bay property in the 19° curve, number 2 track, west of the main car shop.

4.2 Table 4.1 details dates of tests, car configuration, dry/wet rail condition, run number. Runs omitted from the table, i.e. 1 thru 15 and 31 thru 35 were check-out runs prior to each test session.

DATE OF TEST	CAR CONFIGURATION	RAIL CONDITION	RUN NUMBER
20 May 1983	Loaded	Wet	16 thru' 30
21 May 1983	Loaded	Dry	36 thru' 60
21 May 1983	Empty	Dry	61 thru' 85

TABLE 4.1: TESTING FORMAT

4.3 The measurements were made while the consist was pushed in a westerly direction, unmodified car leading.

4.4 Figure 4.1 depicts the general layout of the test set-up.

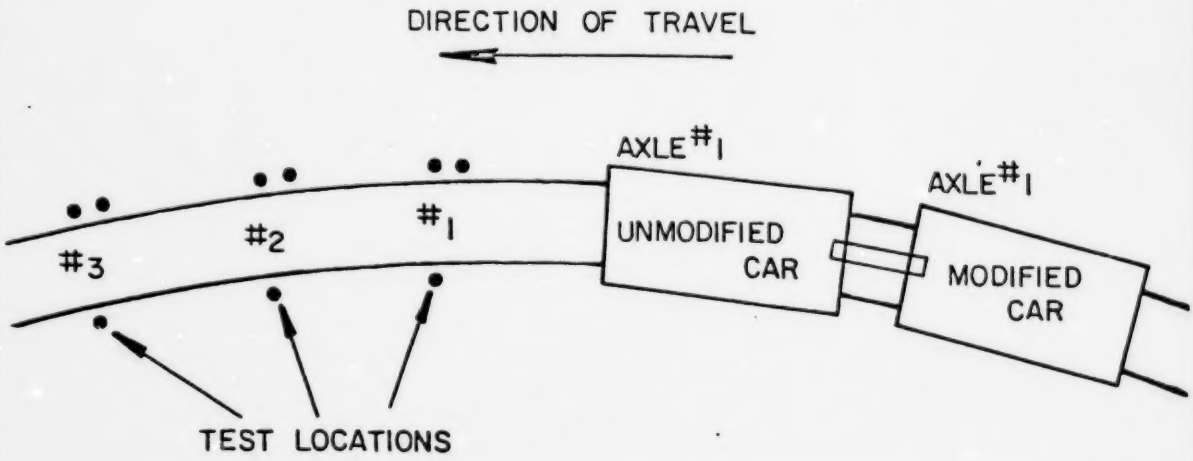


FIGURE 4.1: TEST SET-UP

5.0 TEST PROCEDURES

With equipment set up as detailed in Section 4.0 and the computer suitably programmed, operation of the axle angle measurement equipment is largely automatic, as follows:

- The computer is set to "RUN", at which command the system is ready to receive data.
- The test consist is then pushed through the test window, i.e. the instrumented section of track.
- As the on-board axle position reference arms traverse the trackside sensors the appropriate time intervals are entered into the computer and stored.
- When both axles to be measured have traversed all sets of trackside sensors the data is displayed on the computer monitor. It is then calculated and the results, axle velocity and axle angle, are displayed, and can be printed for future reference.
- The system resets and is again ready to receive data.

The speed at which the test consist traversed the test window was controlled only by the operator of the pushing vehicle. The aim was to maintain constant speed throughout each individual run.

At the completion of each run the consist was reversed through the test section and prepared for the next run.

6.0 METHOD OF ANALYSIS

6.1 DESCRIPTION

For every run the axle velocity and axle angle is computed for both modified truck and unmodified truck for each of the three test locations comprising the test window.

For each run the difference in axle angle between modified and unmodified is calculated and expressed as a percentage.

The average angle of each axle at each test location for each truck configuration is calculated, as is the standard deviation.

Axle angle of attack is plotted against velocity, per measurement site.

6.2 DEFINITIONS

Axle angle of attack is the angle between the long axis of the axle and the tangent to the track. The negative sign is arbitrarily given to angles associated with understeering, while oversteering angles are said to be positive.

6.3 METHODS OF REDUCTION

6.3.1 Velocity

Velocity (V) is calculated:

$V = d/t$

Where:

d is the measured distance between outer trackside sensors and t is the timed interval taken for the on-board reference arm to pass between them.

6.3.2 Angle of Attack

Angle (α) is calculated:

$$\alpha = \tan^{-1} [d/D \ (t_1/t - 1)]$$

where D is the measured distance between radial trackside sensors and t_1 is the timed interval for the inner sensor.

7.0 RESULTS

7.1 The results are shown in Figures 7.1 through 7.9 in Appendix A and Tables A1 through A9.

7.2 On wet rail (Figures 7.1, 7.2, 7.3), the leading axle of the modified truck produced angles of attack of one-half the magnitude of the unmodified truck and appeared to exceed that ratio with increasing speed (The curves through the data points in all figures is a linear least squares fit.

7.3 On dry rail, fully laden, (Figures 7.4, 7.5, 7.6) the modified truck outperformed the unmodified truck by 23-30 percent at 1 m/s decreasing slightly as the speed increased.

7.4 On dry rail, with empty cars (Figures 7.7, 7.8, 7.9), again the modified trucks showed improved angles of attack some 33-40 percent at 1 m/s. Based on the curve fit, the improvement appears to decrease with increasing speed.

FIGURE 7.1: LOADED, WET RAIL, TEST LOCATION #1, MAY 20/83

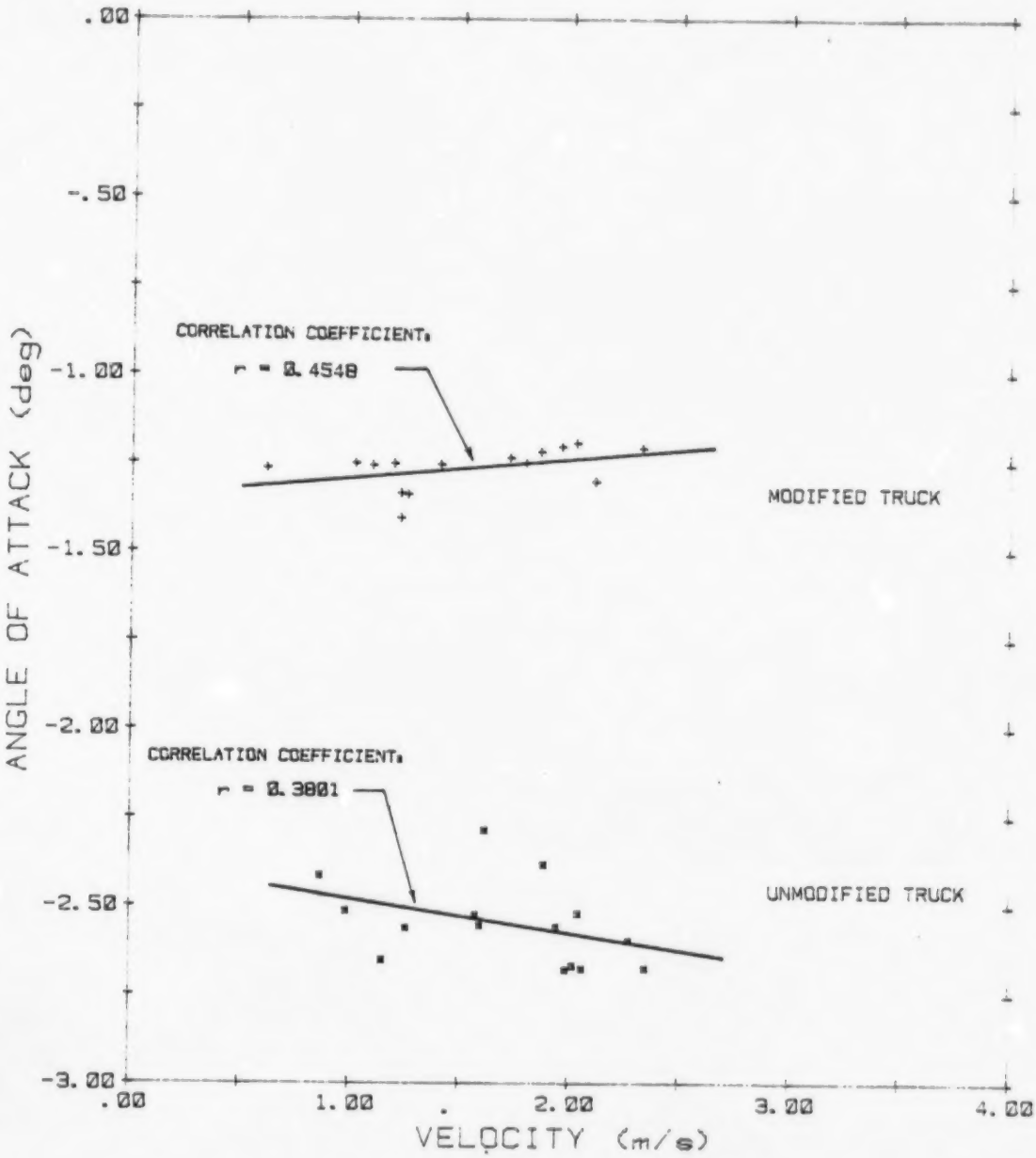


FIGURE 7.2: LOADED, WET RAIL, TEST LOCATION #2, MAY 20/83

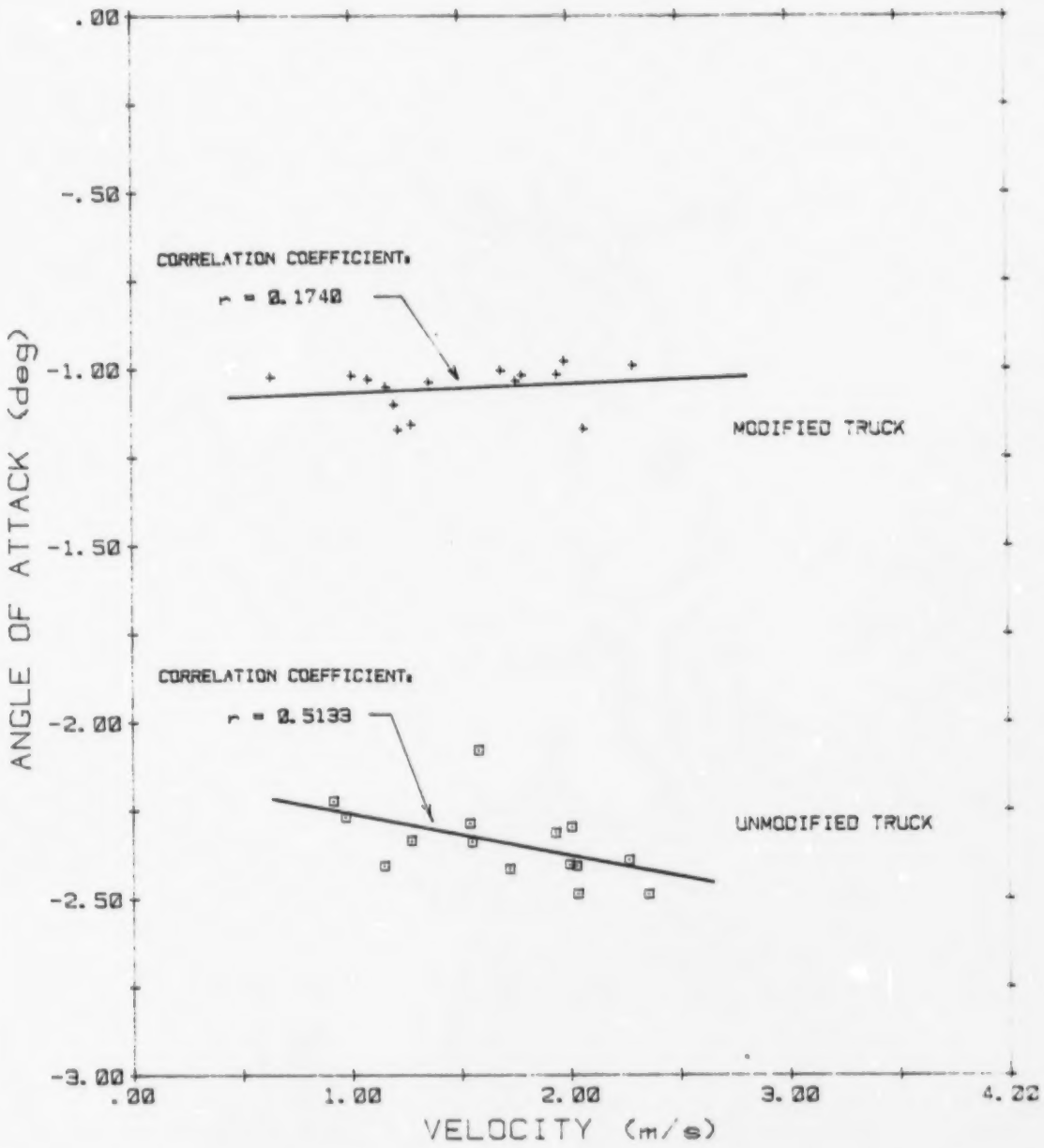


FIGURE 7.3: LOADED, WET RAIL, TEST LOCATION #3, MAY 20/83

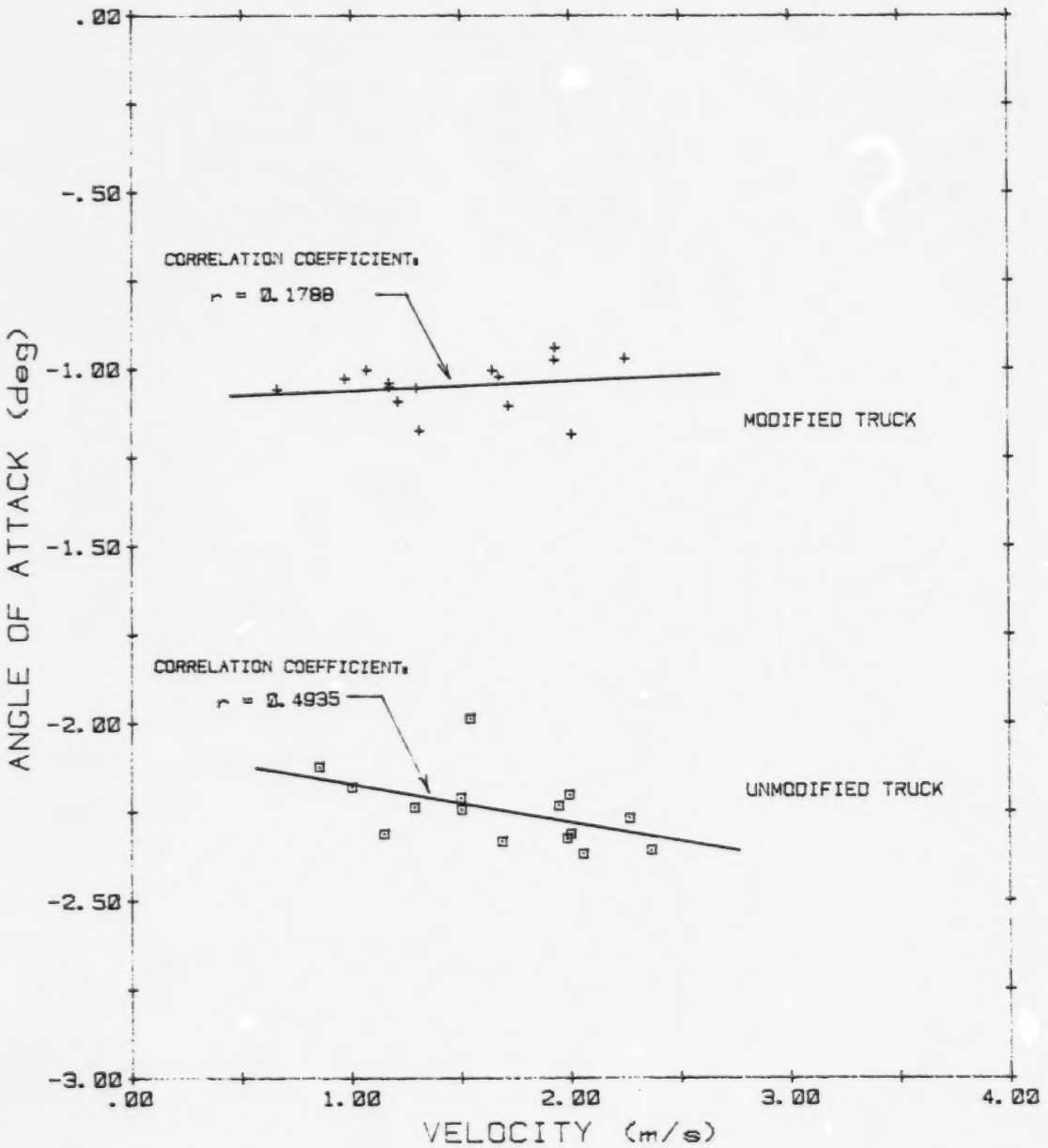


FIGURE 7.4: LOADED, DRY RAIL, TEST LOCATION #1, MAY 20/83

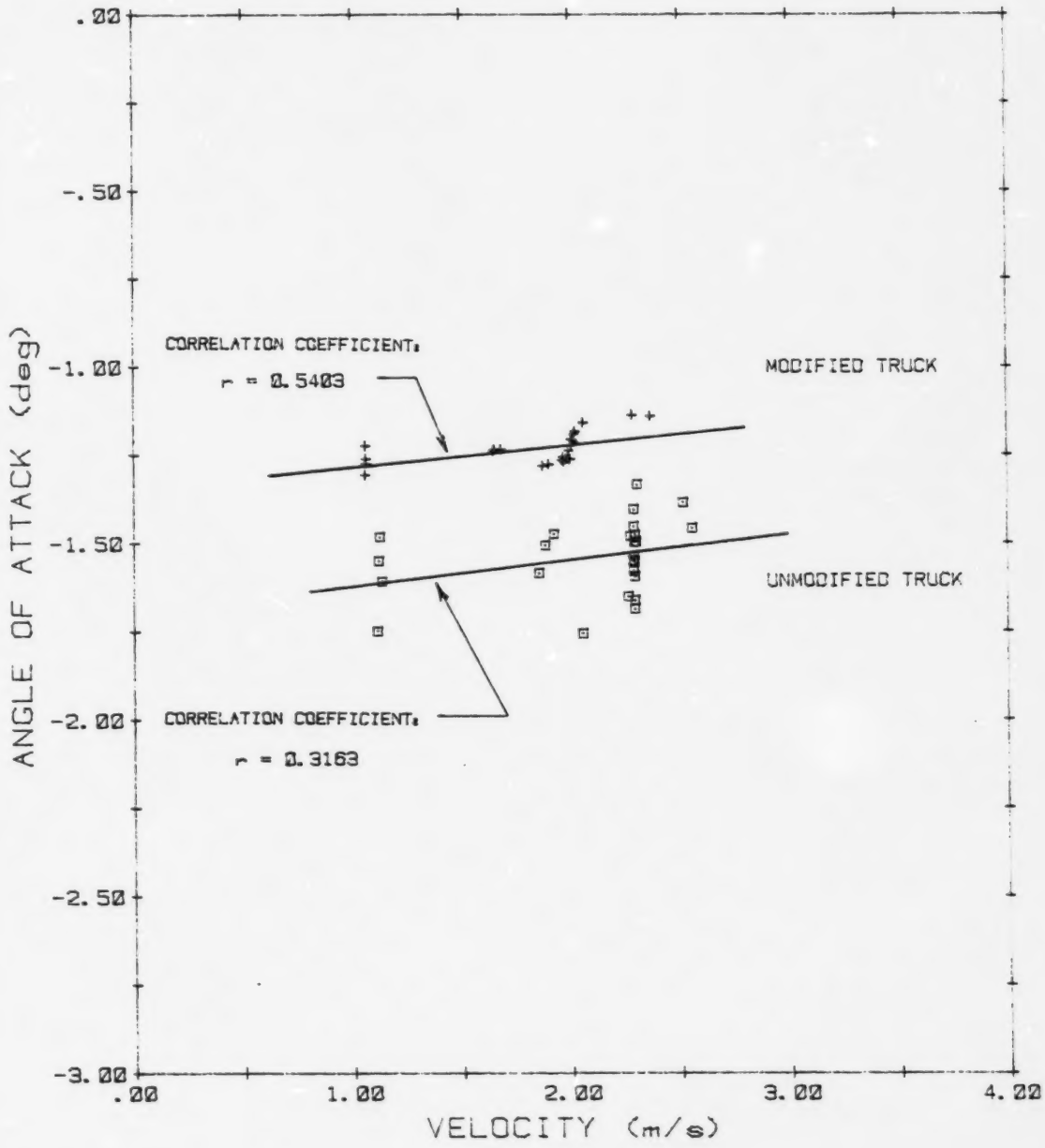


FIGURE 7.5: LOADED, DRY RAIL, TEST LOCATION #2, MAY 20/83

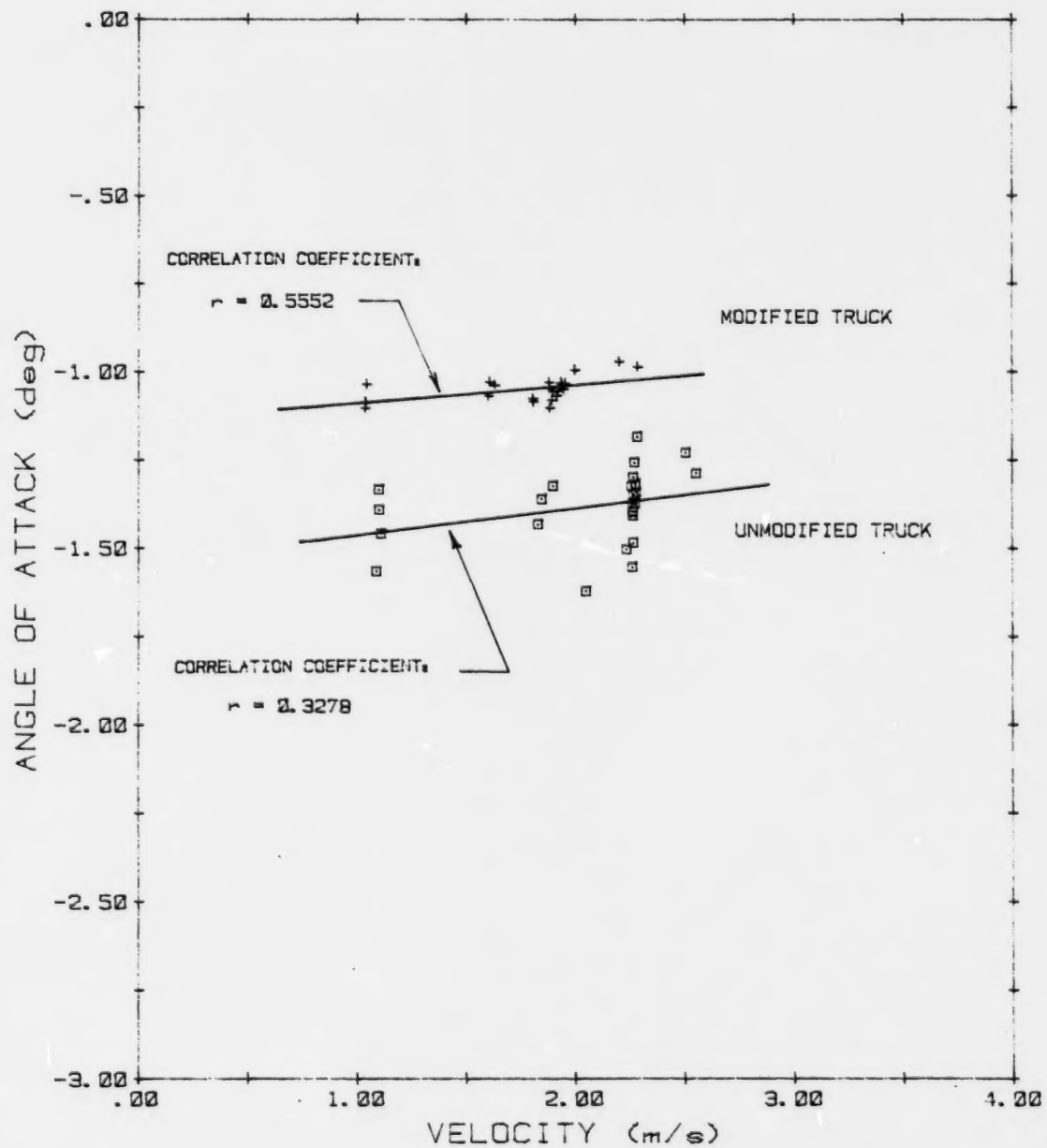


FIGURE 7.6: LOADED, DRY RAIL, TEST LOCATION #3, MAY 20/83

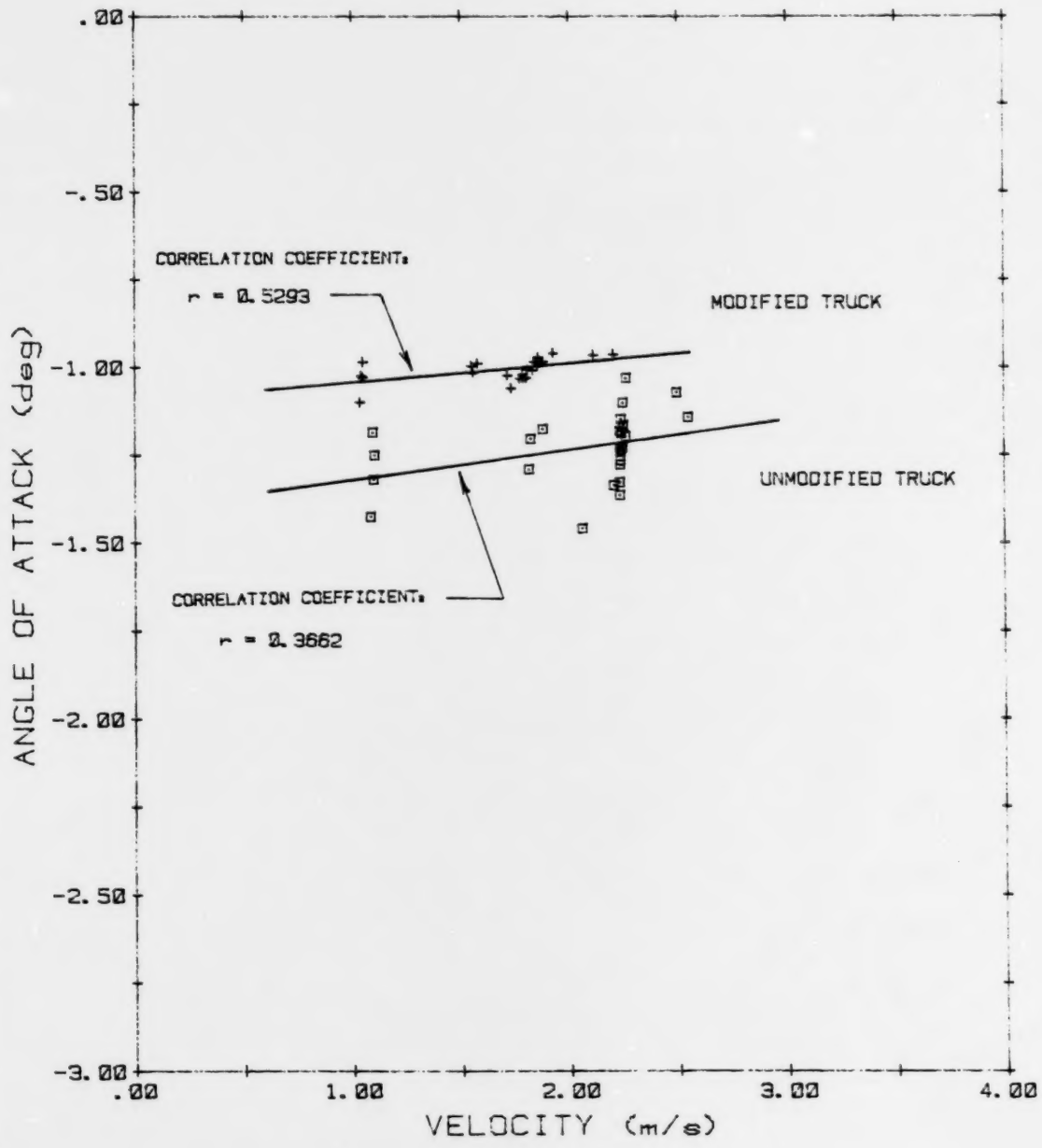


FIGURE 7.7: EMPTY, DRY RAIL, TEST LOCATION #1, MAY 21/83

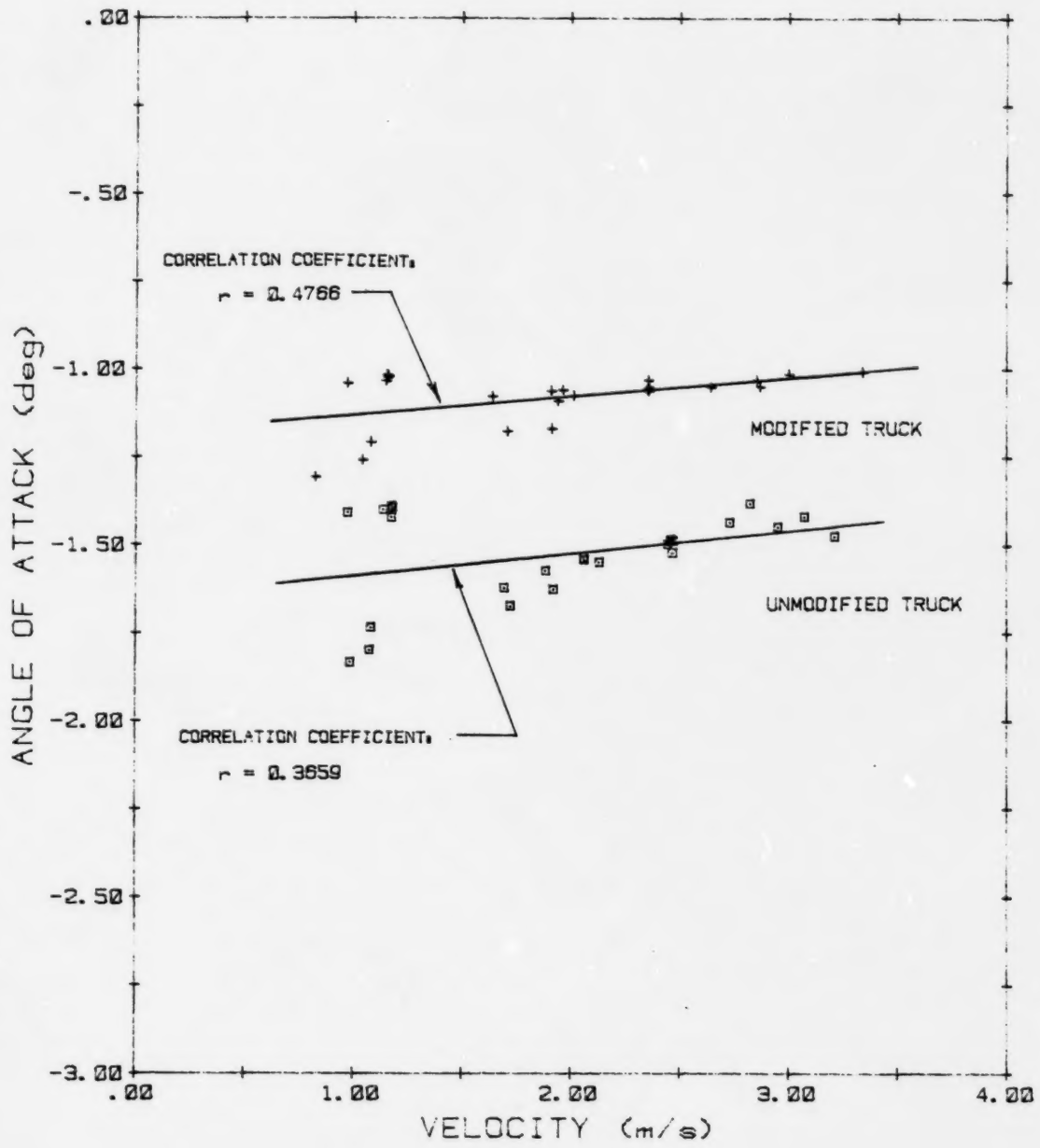


FIGURE 7.8: EMPTY, DRY RAIL, TEST LOCATION #2, MAY 21/83

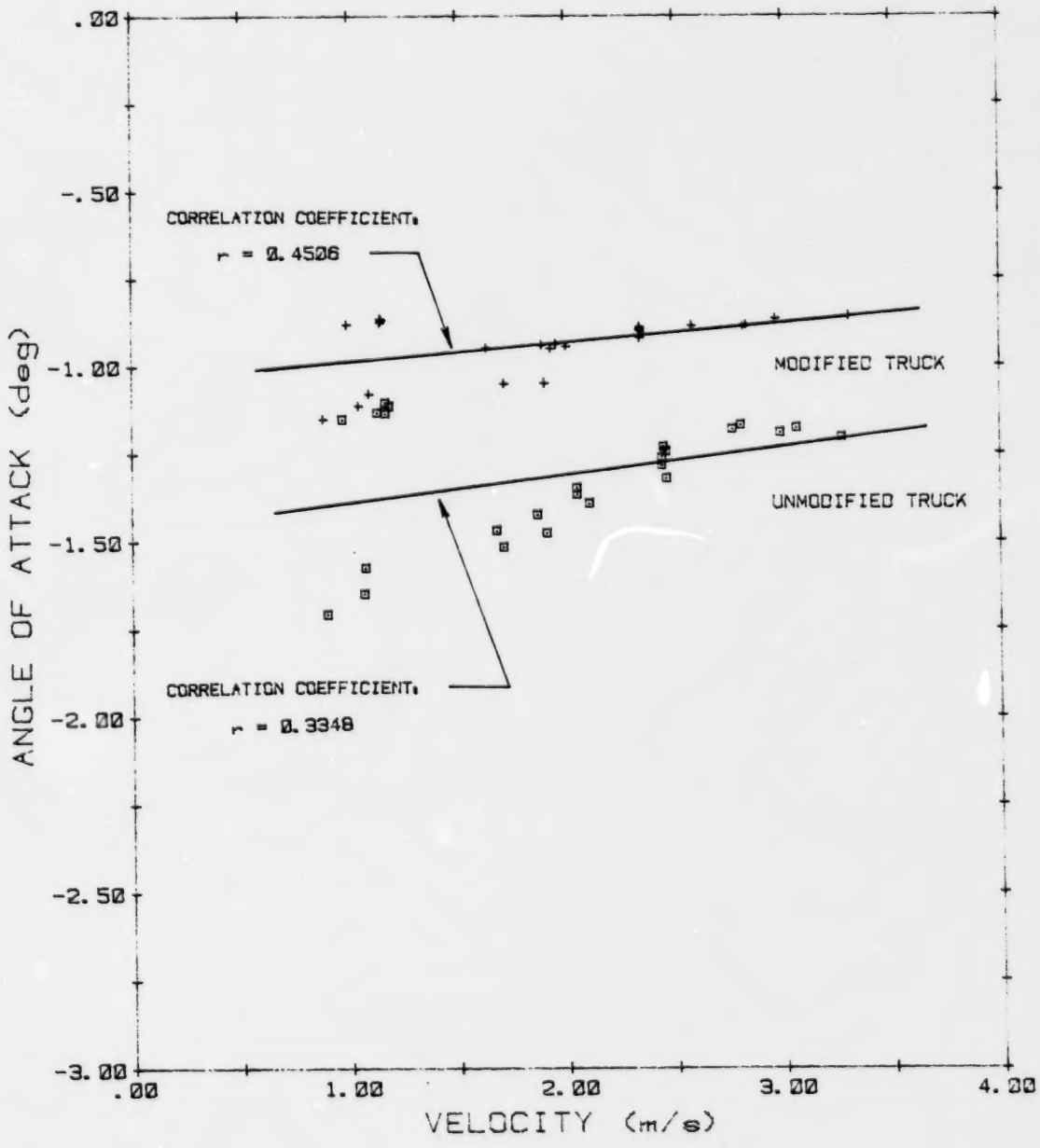
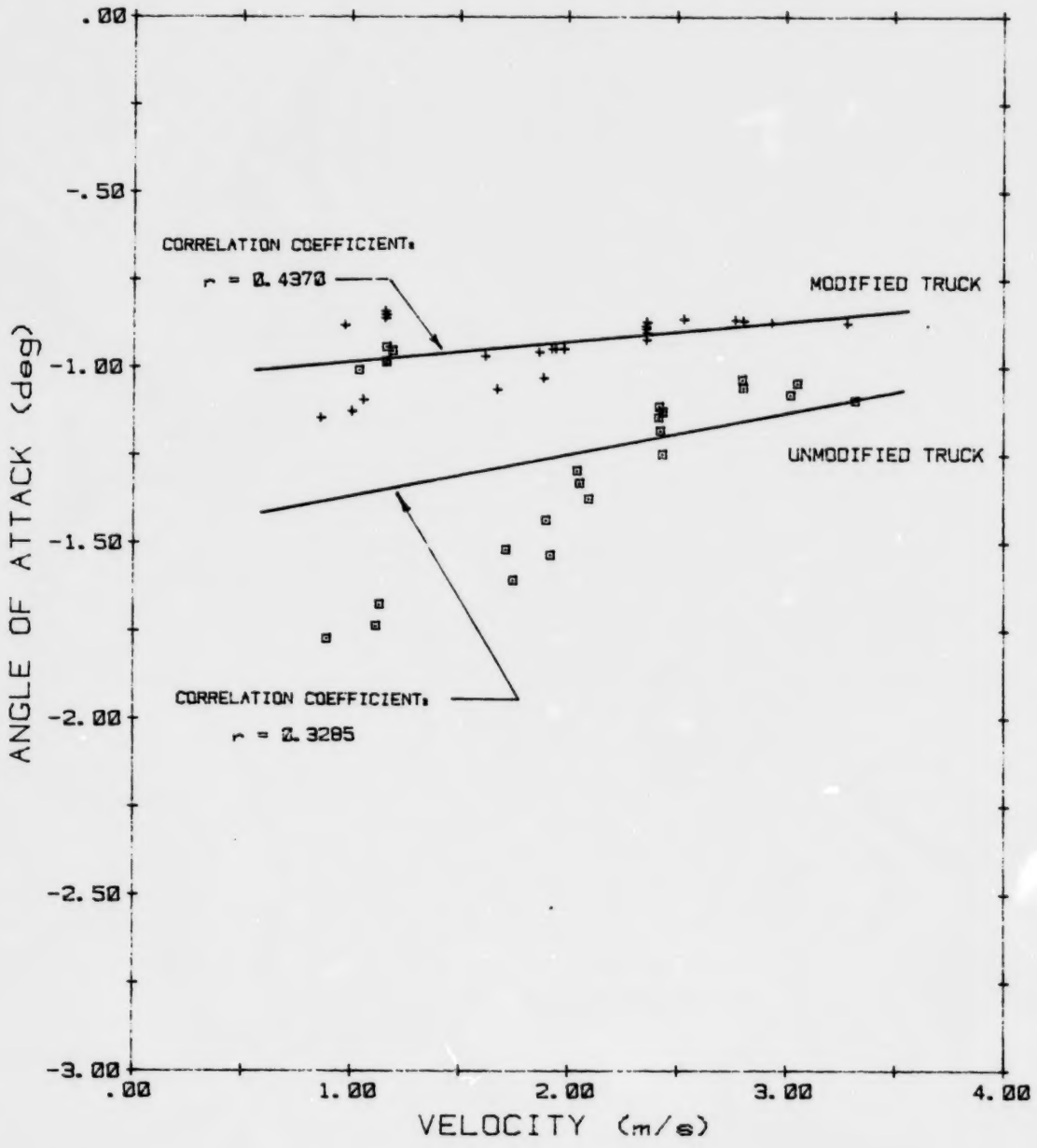


FIGURE 7.9: EMPTY, DRY RAIL, TEST LOCATION #3, MAY 21/83



8.0 DISCUSSION

8.1 COMPARISON - MODIFIED VS UNMODIFIED

The results leave little doubt that the angles of attack produced by the #1 axle of the modified truck are significantly less (therefore better than) those produced by the unmodified truck on the 19 degree curve. In every case the improvement exceeds 20 percent in the measurement range.

It should be cautioned that the trends shown by the curves are the result of relatively few data points and linear curve fitting and should not be taken as the accepted relationship nor extrapolated.

A comparison of the unmodified laden cars with wet and dry rail show that the dry rail results are significantly better than the wet. It is apparent that the creep forces occurring in the wet conditions were far less than those in the dry hence hindering the coned wheels from proper self steering.

A comparison of the modified truck steering and the unmodified truck steering under wet conditions show that, although creep forces may be saturated for both, the motion-opposing flange/rail action produced sufficient forces to cause lozenging in the unmodified truck frame, but was limited by the frame braces from producing like action in the modified truck.

With the angles of attack reduced by the frame bracing, that wheel/rail wear caused by those angles coupled with wheel/rail forces should also be reduced.

8.2 COMPARISON: TEST VS THEORY

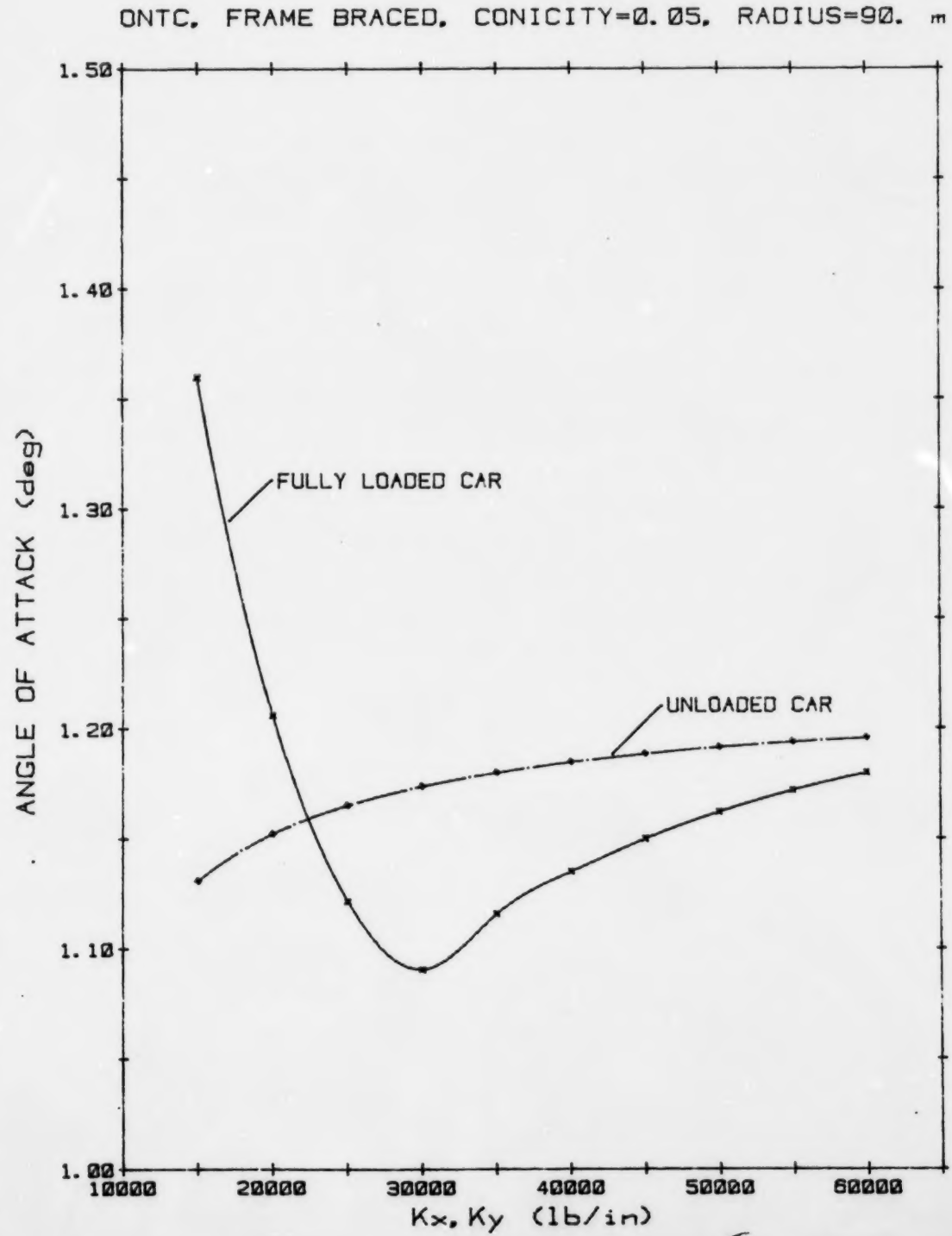
The results of the quasi-linear analysis show that for both the unloaded and loaded conventional all-elastic vehicle on dry rail, the predicted angle of attack on the 19 degree curve is 1.4 degree empty and 4.2 degree loaded. When the standard bolster-to-sideframe stops are considered, the loaded angle is reduced to 2.5 degrees. Based on allowable tolerance that angle could diminish further.

For the modified trucks, (Figure 8.1) the predicted angles of attack for K_x, K_y of 25000 lb/in are 1.14 (loaded) and 1.16 (unloaded), virtually equal and in the range of those angles measured. The measured smaller angle produced by the empty car over the loaded car is not predicted except at K_x, K_y less than 22000 lb/in which is below the rated stiffness for the primary suspension and that measured for the secondary suspension.

Nonetheless, the predicted angles and the measured angles of the modified trucks are in very close agreement.

It should be noted that the predictions show that all outer wheels are flanged on the conventional trucks but that wheels on axles 1 and 3 only are flanged on the frame-braced trucks.

FIGURE 8.1: PREDICTED ANGLE OF ATTACK - MODIFIED TRUCK



9.0 CONCLUSIONS

From the tests carried out, it can be concluded that:

- the angles of attack produced by the frame-braced truck are significantly less than those produced by conventional trucks on both dry and wet rail; and

- the angles of attack produced by the frame-braced trucks are in agreement with theoretical predictions.

APPENDIX A

TABULAR TEST RESULTS

TABLE A1:

LOADED, WET RAIL, TEST LOCATION #1, 20 MAY 83

RUN	UNMODIFIED VEL(m/s)	UNMODIFIED ANGLE(deg)	MODIFIED VEL(m/s)	MODIFIED ANGLE(deg)	ANGLE DIFFERENCE(%)
16	1.6138	-2.2873	1.1948	-1.2341	-46.17
17	1.8856	-2.3829	1.4065	-1.2566	-47.27
18	1.9843	-2.6796	1.8646	-1.2200	-54.47
19	2.0596	-2.6762	1.7241	-1.2369	-53.78
20	.8644	-2.4157	.6131	-1.2662	-47.58
21	.9838	-2.5147	1.0174	-1.2531	-50.17
22	1.1488	-2.6530	1.0965	-1.2594	-52.53
23	1.2562	-2.5620	1.2260	-1.3374	-47.80
24	1.5738	-2.5260	1.2281	-1.4073	-44.29
25	1.5951	-2.5552	1.2573	-1.3399	-47.56
26	2.2726	-2.5977	2.1149	-1.3028	-49.85
27	2.0413	-2.5212	1.7977	-1.2510	-50.38
28	1.9427	-2.5592	1.9606	-1.2054	-52.90
29	2.0178	-2.6685	2.0274	-1.1754	-55.20
30	2.3469	-2.6749	2.3268	-1.2097	-54.78
AVERAGE ANGLES:		-2.5516		-1.2663	
STDS:		.1174		.0531	

TABLE A2:

LOADED, WET RAIL, TEST LOCATION #2, 20 MAY 83

RUN	UNMODIFIED VEL(m/s)	UNMODIFIED ANGLE(deg)	MODIFIED VEL(m/s)	MODIFIED ANGLE(deg)	ANGLE DIFFERENCE(%)
16	1.3821	-2.0801	1.1616	-1.0520	-49.43
17	1.7219	-2.4160	1.3538	-1.0380	-57.04
18	1.9553	-2.4030	1.7863	-1.0187	-57.61
19	2.0269	-2.4068	1.6894	-1.0054	-58.23
20	.9164	-2.2238	.8350	-1.0233	-73.98
21	.9721	-2.2691	1.0039	-1.0190	-55.09
22	1.1473	-2.4062	1.0794	-1.0306	-57.16
23	1.2709	-2.3349	1.1987	-1.1023	-52.79
24	1.5400	-2.3862	1.2161	-1.1731	-48.69
25	1.5507	-2.3404	1.2787	-1.1581	-50.52
26	2.2667	-2.3909	2.0651	-1.1716	-51.00
27	2.0055	-2.2972	1.7567	-1.0353	-54.93
28	1.9325	-2.3131	1.9468	-1.0170	-56.03
29	2.0325	-2.4862	1.9810	-.9778	-60.69
30	2.3555	-2.4871	2.2932	-.9815	-60.53
AVERAGE ANGLES:		-2.3427		-1.0243	-56.24%
STDS:		.1034		.0249	

TABLE A3:

LOADED. JET RAIL. TEST LOCATION #3. 20 MAY 83

	UNMODIFIED		MODIFIED		ANGLE
RUN	VEL(m/s)	ANGLE(deg)	VEL(m/s)	ANGLE(deg)	DIFFERENCE %
16	1.5426	-1.9676	1.1713	-1.0320	-47.07
17	1.6681	-2.3339	1.2982	-1.0553	-54.78
18	2.0003	-2.3130	1.6764	-1.0234	-55.75
19	1.9842	-2.3253	1.6464	-1.0034	-56.7e
20	.8531	-2.1239	.8623	-1.0589	-50.1e
21	1.0030	-2.1822	.9712	-1.0291	-52.8?
22	1.1496	-2.3132	1.0893	-1.0633	-5e.53
23	1.2891	-2.2386	1.1712	-1.0411	-53.49
24	1.5001	-2.2108	1.2135	-1.0932	-50.55
25	1.5034	-2.2443	1.3118	-1.17e1	-47.e1
26	2.2e79	-2.2686	2.0079	-1.1855	-47.74
27	1.9946	-2.2024	1.7191	-1.1060	-49.??
28	1.9471	-2.2334	1.9310	-.9763	-5e.28
29	2.0567	-2.3e86	1.9332	-.9414	-e0.25
30	2.3e71	-2.3583	2.2521	-.9727	-58.75
AVERAGE ANGLES:		-2.2470		-1.0479	- ?? 3e ?
STDS:		.1201		.0696	

TABLE A4:

LOADED, ON RAIL, TEST LOCATION #1, 21 MAY 83

RUN	UNMODIFIED VEL(m/s)	UNMODIFIED ANGLE(deg)	MODIFIED VEL(m/s)	MODIFIED ANGLE(deg)	ANGLE DIFFERENCE(%)
36	1.1103	-1.7501	1.0570	-1.3074	-25.30
37	2.0535	-1.7560	1.8709	-1.2628	-28.95
38	2.3927	-1.6869	1.9593	-1.2654	-24.98
39	2.2935	-1.6623	1.9694	-1.2731	-23.41
40	2.2608	-1.6509	1.8992	-1.2783	-22.57
41	2.2928	-1.5945	1.9795	-1.2629	-20.80
42	2.2865	-1.5793	1.9650	-1.2574	-20.38
43	2.2908	-1.5341	1.9662	-1.2578	-19.97
44	2.2909	-1.5355	1.9983	-1.2664	-17.72
45	2.2833	-1.5500	1.9896	-1.2387	-20.08
46	1.1178	-1.5505	1.0602	-1.2622	-18.59
47	1.1322	-1.6094	1.0574	-1.2752	-20.77
48	1.8539	-1.5855	1.6441	-1.2399	-21.80
49	1.9227	-1.4752	1.6814	-1.2361	-16.19
50	1.8834	-1.5076	1.6806	-1.2351	-18.08
51	1.1230	-1.4822	1.0575	-1.2249	-17.36
52	2.2980	-1.4972	2.0135	-1.2149	-18.86
53	2.2898	-1.4963	2.0044	-1.2240	-18.31
54	2.2728	-1.4814	2.0060	-1.2074	-18.50
55	2.2933	-1.4787	2.0139	-1.1924	-19.36
56	2.2881	-1.4541	2.0002	-1.2081	-16.92
57	2.2880	-1.4060	2.0190	-1.1856	-15.68
58	2.3039	-1.3355	2.0564	-1.1609	-13.07
59	2.5136	-1.3871	2.2811	-1.1394	-17.86
60	2.5557	-1.4594	2.3641	-1.1426	-21.71
AVERAGE ANGLES:		-1.5411		-1.2335	-19.97
STDs:		.1036		.0439	

TABLE A5:

LOADED. DRY RAIL. TEST LOCATION #2, 21 MAY 83

RUN	UNMODIFIED VEL(m/s)	UNMODIFIED ANGLE(deg)	MODIFIED VEL(m/s)	MODIFIED ANGLE(deg)	ANGLE DIFFERENCE(%)
36	1.0884	-1.5654	1.0387	-1.1041	-29.47
37	2.0481	-1.6209	1.8086	-1.0860	-33.00
38	2.2608	-1.5525	1.8810	-1.0316	-33.55
39	2.2643	-1.4837	1.8982	-1.0560	-28.83
40	2.2341	-1.5028	1.8058	-1.0778	-28.28
41	2.2624	-1.3943	1.8931	-1.0819	-22.41
42	2.2635	-1.4075	1.8830	-1.1037	-21.58
43	2.2620	-1.3728	1.8828	-1.0485	-23.62
44	2.2732	-1.3739	1.9166	-1.0685	-22.23
45	2.2622	-1.3977	1.9195	-1.0561	-24.44
46	1.1015	-1.3907	1.0385	-1.0871	-21.85
47	1.1113	-1.4585	1.0419	-1.0889	-25.34
48	1.8300	-1.4319	1.6026	-1.0692	-25.30
49	1.8986	-1.3242	1.6089	-1.0302	-22.20
50	1.8467	-1.3619	1.6332	-1.0394	-23.68
51	1.1014	-1.3337	1.0454	-1.0363	-22.28
52	2.2796	-1.3420	1.9465	-1.0506	-21.71
53	2.2673	-1.3475	1.9352	-1.0328	-23.35
54	2.2577	-1.3252	1.9368	-1.0336	-22.00
55	2.2750	-1.3183	1.9391	-1.0363	-21.39
56	2.2649	-1.2995	1.9356	-1.0423	-19.79
57	2.2709	-1.2575	1.9544	-1.0337	-17.80
58	2.2838	-1.1849	1.9985	-.9959	-15.95
59	2.5053	-1.2303	2.2000	-.9720	-20.99
60	2.5532	-1.2890	2.2844	-.9871	-23.42
AVERAGE ANGLES:		-1.3827		-1.0500	-24.05%
STDS:		.1047		.0349	

TABLE A6:

LOADED, DRY RAIL, TEST LOCATION #3, 21 Apr 83

RUN	UNMODIFIED VEL(m/s)	UNMODIFIED ANGLE(deg)	MODIFIED VEL(m/s)	MODIFIED ANGLE(deg)	ANGLE DIFFERENCE(%)
36	1.0818	-1.4254	1.0338	-1.0997	-22.85
37	2.0552	-1.4594	1.7313	-1.0e22	-27.22
38	2.2288	-1.3e48	1.7714	-1.034e	-24.19
39	2.2291	-1.3284	1.8007	-1.0322	-22.30
40	2.2005	-1.33e5	1.7129	-1.0251	-23.30
41	2.2308	-1.3782	1.8070	-1.0089	-21.07
42	2.2327	-1.26e4	1.7826	-1.0129	-19.13
43	2.2321	-1.2378	1.7877	-1.0344	-16.43
44	2.2427	-1.2313	1.8320	-1.0103	-17.95
45	2.2330	-1.2352	1.83e4	-.98e8	-20.11
46	1.1006	-1.2515	1.0399	-1.024e	-18.13
47	1.0967	-1.3203	1.04e3	-1.0297	-22.01
48	1.8121	-1.2920	1.5553	-1.0179	-21.22
49	1.8770	-1.1775	1.5477	-.9978	-15.2e
50	1.8196	-1.2061	1.57e4	-.9904	-17.8E
51	1.0925	-1.1856	1.0477	-.9852	-1e.90
52	2.2573	-1.1988	1.8646	-.9874	-17.e3
53	2.2375	-1.1897	1.8556	-.9734	-18.18
54	2.2342	-1.1825	1.855e	-.9825	-16.91
55	2.24e9	-1.1e70	1.8e15	-.9868	-15.44
56	2.2345	-1.1500	1.8536	-.9757	-15.42
57	2.2451	-1.1028	1.8786	-.985e	-10.e3
58	2.2601	-1.0326	1.9245	-.9618	-6.8e
59	2.4925	-1.0740	2.1087	-.9e79	-4.8e
60	2.5445	-1.1439	2.2008	-.9555	-10.60
AVERAGE ANGLES:		-1.2335		-1.00e8	- [illegible] %
STDS:		.1027		.0323	

TABLE A7:

EMPTY, DRY RAIL, TEST LOCATION #1, 21 MAY 83

	UNMODIFIED		MODIFIED		ANGLE
RUN	VEL(m/s)	ANGLE(deg)	VEL(m/s)	ANGLE(deg)	DIFFERENCE(%)
61	.9851	-1.8343	.8271	-1.3075	-28.72
62	1.0740	-1.7988	1.0434	-1.2590	-30.01
63	1.0812	-1.7345	1.0819	-1.2078	-30.37
64	1.7234	-1.6726	1.7120	-1.1774	-29.61
65	1.9211	-1.6251	1.9150	-1.1701	-28.00
66	1.6946	-1.6215	1.6410	-1.0783	-33.50
67	1.8853	-1.5724	1.9123	-1.0629	-32.40
68	2.1314	-1.5486	1.9652	-1.0605	-31.52
69	2.0623	-1.5408	2.0159	-1.0763	-30.15
70	2.0594	-1.5401	1.9434	-1.0918	-29.11
71	2.4676	-1.5225	2.3582	-1.0516	-30.93
72	2.4451	-1.4974	2.3580	-1.0632	-29.00
73	2.4582	-1.4877	2.3587	-1.0572	-28.94
74	2.4712	-1.4887	2.3512	-1.0574	-28.97
75	2.4581	-1.4838	2.3575	-1.0315	-30.48
76	3.2114	-1.4741	3.3403	-1.0080	-31.62
77	2.9501	-1.4479	3.0013	-1.0143	-29.95
78	2.7296	-1.4359	2.8540	-1.0312	-28.18
79	3.0719	-1.4184	2.8680	-1.0499	-25.98
80	2.8224	-1.3817	2.6423	-1.0516	-23.89
81	.9742	-1.4084	.9732	-1.0405	-26.12
82	1.1767	-1.4223	1.1510	-1.0334	-27.34
83	1.1390	-1.4002	1.1625	-1.0200	-27.15
84	1.1768	-1.3901	1.1588	-1.0243	-26.31
85	1.1805	-1.3937	1.1564	-1.0170	-27.03
AVERAGE ANGLES:		-1.5257		-1.0817	-2[illegible]
STDS:		.1271		.0793	

TABLE A8:

EMPTY, DRY RAIL, TEST LOCATION #2, 21 MAY 83

	UNMODIFIED		MODIFIED		ANGLE
RUN	VEL(m/s)	ANGLE(deg)	VEL(m/s)	ANGLE(deg)	DIFFERENCE(%)
61	.8944	-1.7068	.8796	-1.1518	-32.52
62	1.0642	-1.6471	1.0427	-1.1135	-32.40
63	1.0713	-1.5733	1.0917	-1.0800	-31.35
64	1.7088	-1.5146	1.7161	-1.0514	-30.58
65	1.9081	-1.4753	1.9010	-1.0496	-28.86
66	1.6777	-1.4678	1.6355	-.9484	-35.39
67	1.8664	-1.4236	1.8899	-.9419	-33.84
68	2.1044	-1.3920	1.9546	-.9382	-32.60
69	2.0478	-1.3660	2.0014	-.9450	-30.82
70	2.0475	-1.3482	1.9298	-.9514	-29.43
71	2.4603	-1.3214	2.3386	-.9203	-30.35
72	2.4392	-1.2834	2.3421	-.9037	-29.59
73	2.4397	-1.2619	2.3393	-.8959	-29.00
74	2.4585	-1.2447	2.3358	-.8970	-27.93
75	2.4464	-1.2310	2.3403	-.8903	-27.68
76	3.2700	-1.2050	3.3054	-.8599	-28.64
77	2.9862	-1.1912	2.9652	-.8668	-27.23
78	2.7641	-1.1810	2.8302	-.8851	-25.06
79	3.0618	-1.1780	2.8158	-.8875	-24.66
80	2.8031	-1.1699	2.5788	-.8871	-24.17
81	.9674	-1.1513	.9904	-.8814	-23.44
82	1.1684	-1.1347	1.1430	-.8753	-22.86
83	1.1286	-1.1323	1.1469	-.8658	-23.54
84	1.1860	-1.1140	1.1492	-.8685	-22.04
85	1.1677	-1.1039	1.1462	-.8666	-21.50
AVERAGE ANGLES:		-1.3127		-.9369	-28.6
STDS:		.1731		.0844	

TABLE A9:

EMPTY, DRY RAIL, TEST LOCATION #3, 21 MAY 83

	UNMODIFIED		MODIFIED		ANGLE
RUN	VEL(m/s)	ANGLE(deg)	VEL(m/s)	ANGLE(deg)	DIFFERENCE(%)
61	.8687	-1.7727	.8588	-1.1450	-35.41
62	1.1157	-1.7358	1.0031	-1.1270	-35.07
63	1.1312	-1.6746	1.0559	-1.0940	-34.67
64	1.7482	-1.6062	1.6746	-1.0643	-33.74
65	1.9192	-1.5340	1.8882	-1.0321	-32.72
66	1.7156	-1.5183	1.6193	-.9696	-36.14
67	1.9002	-1.4351	1.8686	-.9575	-33.28
68	2.0964	-1.3746	1.9453	-.9482	-31.02
69	2.0536	-1.3295	1.9837	-.9488	-28.63
70	2.0433	-1.2944	1.9270	-.9469	-26.85
71	2.4338	-1.2478	2.3599	-.9225	-26.07
72	2.4242	-1.1807	2.3587	-.9014	-23.66
73	2.4152	-1.1431	2.3560	-.8834	-22.72
74	2.4344	-1.1279	2.3547	-.8906	-21.04
75	2.4189	-1.1124	2.3621	-.8715	-21.67
76	3.3179	-1.0952	3.2816	-.8752	-20.09
77	3.0213	-1.0784	2.9353	-.8735	-19.00
78	2.8046	-1.0584	2.8044	-.8680	-17.99
79	3.0541	-1.0455	2.7683	-.8634	-17.23
80	2.7995	-1.0347	2.5317	-.8636	-16.54
81	1.0362	-1.0081	.9696	-.8809	-12.62
82	1.1609	-.9863	1.1590	-.8500	-13.82
83	1.1632	-.9820	1.1562	-.8407	-14.39
84	1.1918	-.9532	1.1593	-.8503	-10.80
85	1.1632	-.9424	1.1564	-.8606	-8.68
AVERAGE ANGLES:		-1.2509		-.9734	-22.20
STDS:		.2613		.0908	